

# Recent Investigations into Potential Applications for Wireless Technologies at NASA/MSFC

Darren Boyd, Electronic Design Branch  
NASA MSFC  
WISEE 2017

National Aeronautics and  
Space Administration

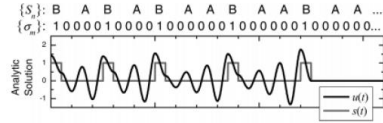


**MARSHALL**  
SPACE FLIGHT CENTER



# Agenda

## Interests and Motivation



Second Generation  
Wireless Sensors



Chaotic Oscillator  
Trajectory Communication

Formation Flying



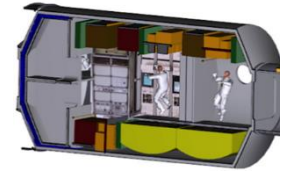
Systems Integration  
Lab (SIL)



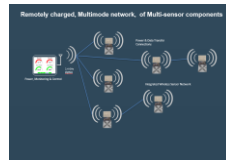
Fuel Tank Wireless  
Power and Signal System



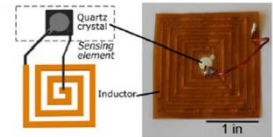
Habitat Control System



Compact Wireless Power  
and Data Sensor System



Passive Wireless  
Strain Sensors



Questions?

# Interests and Motivation

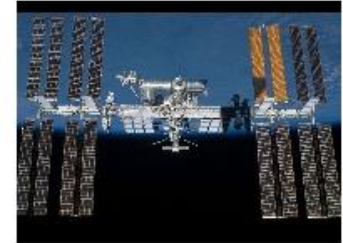
## Ground Systems



## Vehicles/Manned or Unmanned



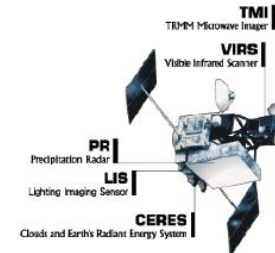
## Habitats



## Surface Exploration



## Satellites/Payloads



# Interests and Motivation

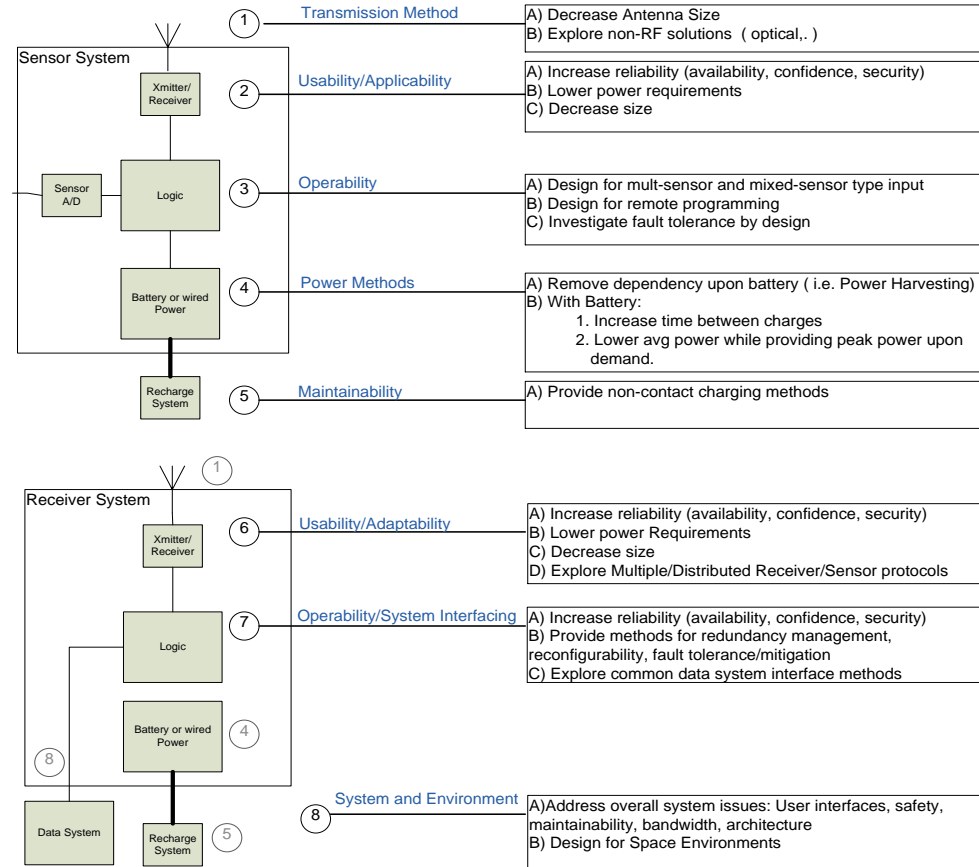


- Ability to get sensor measurements in places not accessible with cabled systems: inside tanks, inside Mars craters, wing leading edges, on systems that are moving.
- Allows adding new sensors quickly and at any point during the entire life cycle - reducing cost and schedule.
- Provides for less wires, connectors, penetrations
  - Fewer Cables == Weight savings!
  - Weight is not just the cables, it is insulation, bundles, brackets, connectors, bulkheads, cable trays, structural attachments, and reinforcement, and of course the resulting impact on payloads/operations.
  - Cable design can be complex and time consuming to create and maintain
  - Cable/Connectors difficult to change with new data requirements.
  - Cables/Connectors can be a source of failure and require mitigation of hazards
  - Cables provide little design flexibility
  - Cables can be a source of noise
- Wireless systems can be configured for alternate paths ( mesh networking) to provide for greater redundancy.



# Wireless Development Approach

The MSFC Wireless Technology Development Process has targeted different focus areas allowing development and application of systems and components to be used across different implementations and to meet varied environment, measurement, and communication requirements.





# Second Generation Wireless Sensors

Kosta Varnavas/ES36

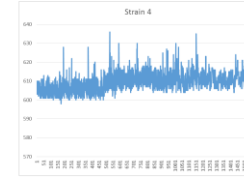
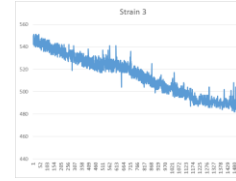
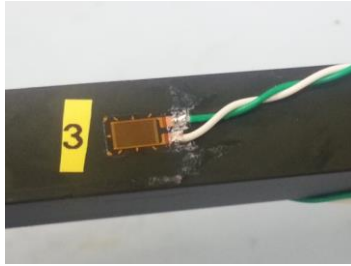
Jeff Richeson/ESSSA

# Technical Overview & Project Scope

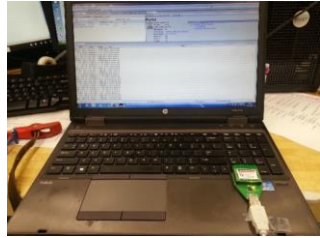


Development of a wireless data acquisition system that can support multiple sensor types to support ground testing and provide a path to flight component development.

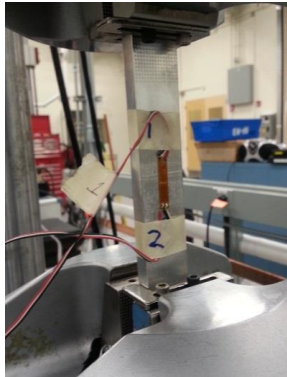
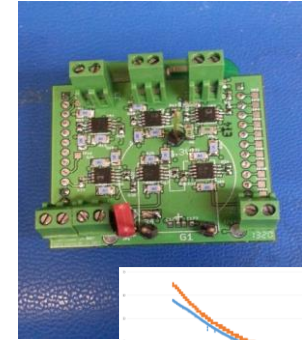
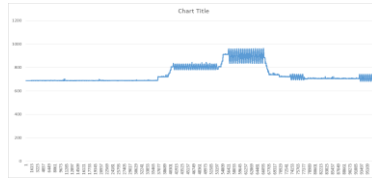
Project developed under several research initiatives. Each generation of development has added new functionality and decrease in size.



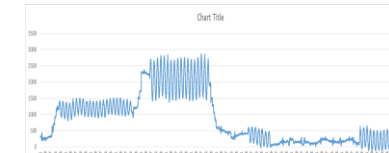
## Wireless strain gauge on quadcopter



## Wireless sensor systems development



## Wireless strain gauge at materials lab pull test



## Materials lab strain gauge pull test



## Combined wireless and reference K-type thermocouple measurements



## Gen 2 Wireless strain gauge

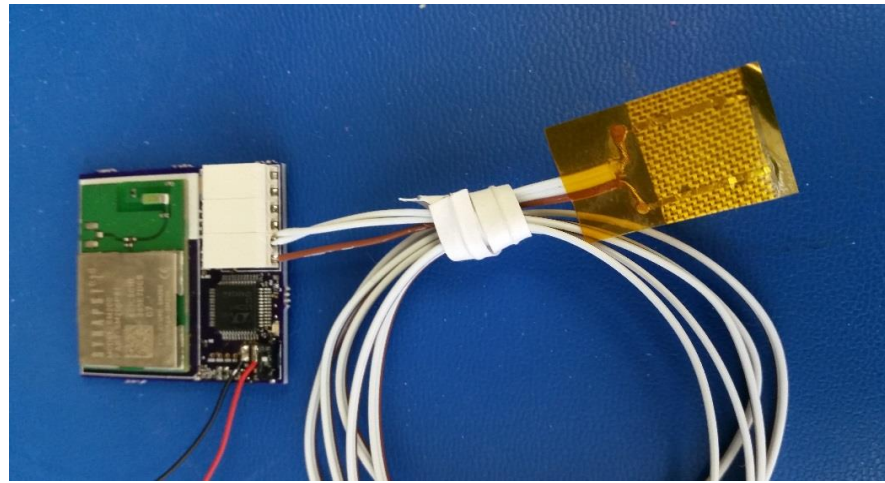
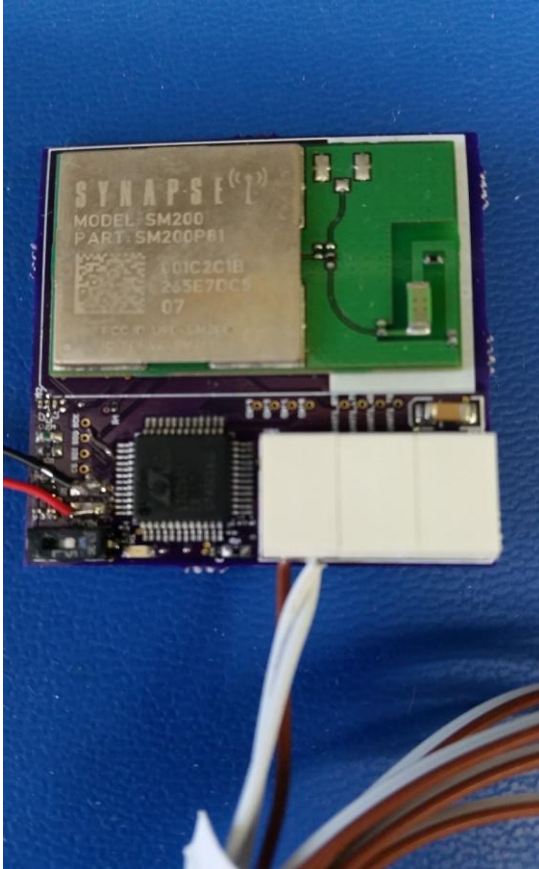
- \* 1 Channel
- \* With Battery
- \* 1.5 " x 1.3 " without case



Gen 2 Wireless  
strain gauge  
with power leads  
and strain gauge  
attached



## Wireless temperature sensor board



With  
RTD

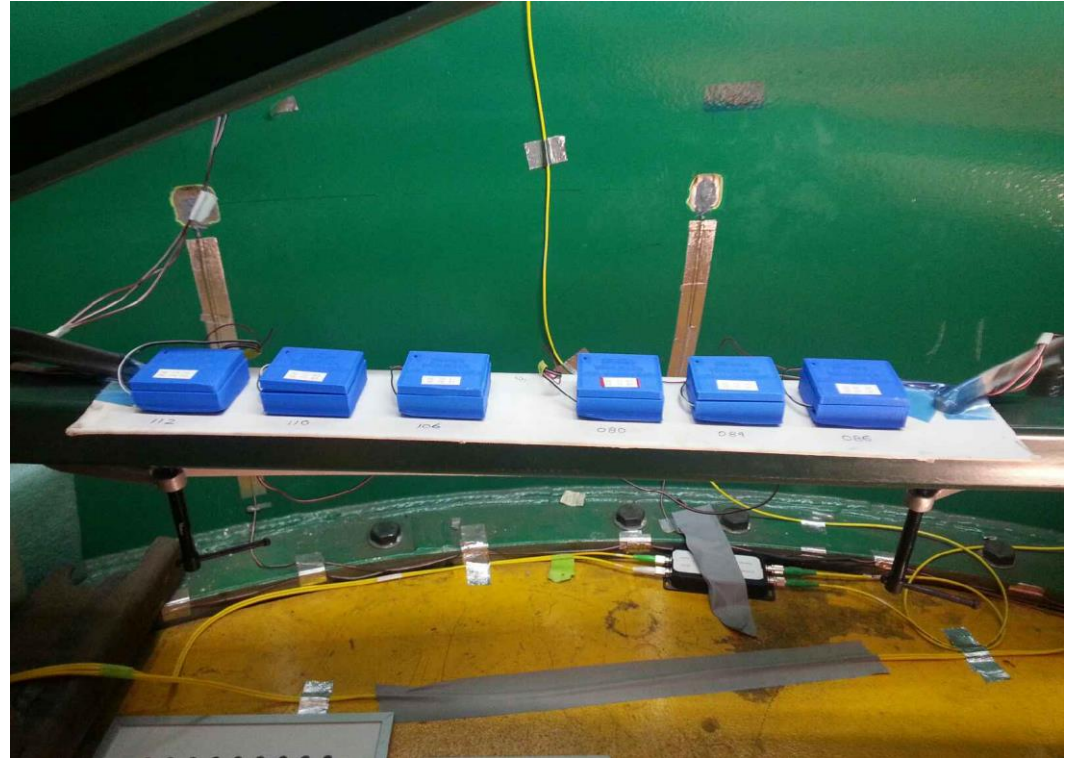
Can measure :

- Virtually all standard (type B, E, J, K, N, S, R, T) or custom thermocouples
- Automatically compensate for cold junction temperatures and linearize the results
- 2-, 3-, or 4-wire RTDs
- Thermistors
- Diodes
- SPI bus controlled

20 – 1 channel MSFC wireless  
sensors inside composite shell



Composite Shell Buckling Test





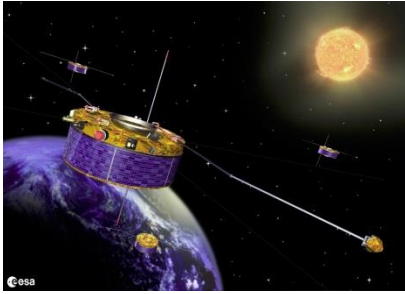


# Formation Flying

Garrick Merrill/ES36

Chris Becker/EV42

# Technical Overview & Project Scope



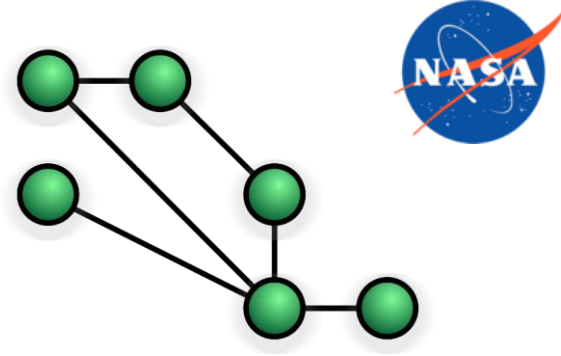
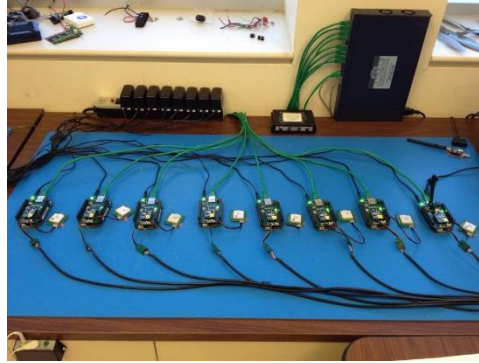
Develop a scalable mesh network between vehicles to share real-time position data and maintain formations autonomously.

The shrinking size of satellites and Unmanned Aerial Vehicles (UAVs) is enabling lower cost missions. As sensors and electronics continue to downsize, the next step is multiple vehicles providing different perspectives or variations for more precise measurements. While flying a single satellite or UAV autonomously is a challenge, flying multiple vehicles in a precise formation is even more challenging.

Initial prototype developed in lab, followed by flight testing on multiple UAVs, followed by orbital simulation of multiple satellites.



# Mesh Network Requirements

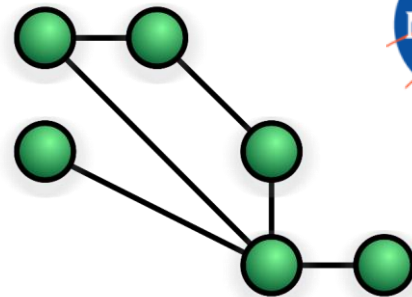


- No single point of failure for network, no master/coordinator nodes
- Nodes can enter & leave the network at any time
- Low latency more important than bandwidth
- Generic interfaces to be hardware agnostic



# Mesh Network Design

- 3rd Gen Design
  - 2.4GHz Xbee radios used
  - FPGA added (Actel ProASIC 3)
    - Mesh network smarts moved from software to VHDL
    - Network timing accuracy improved
    - Flight computer overhead greatly reduced
    - Flight computer can interface to FPGA through standard serial connection and spam data while FPGA handles all mesh network smarts

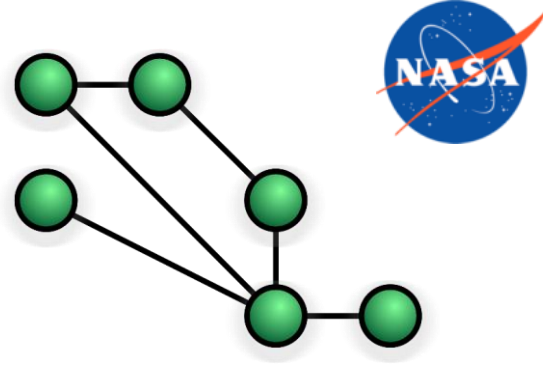


# 3<sup>rd</sup> Gen Complete

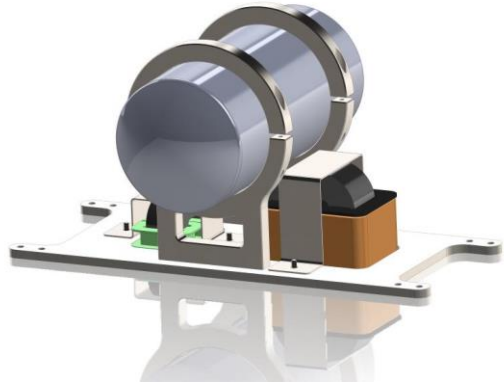
- Six Xbee formation nodes completed
  - BeagleBone Black computer
  - Custom FPGA adapter board
  - Single Xbee Pro radio & GPS
  - Flight testing with 5 quadcopters complete



# Current Development



- Combined work with MAPS to use radio to determine ranging between vehicles and position
- Increasing FPGA capabilities
- Investigating syncing without GPS



# Fuel Tank Wireless Power and Signal Interface System

Garrick Merrill/ES36



# Technical Overview & Project Scope



Eliminate protrusions into fuel/oxidizer tanks for sensor wiring helps simplify tank design, reduces leakage, and increases safety. Avoiding the use of batteries by powering the sensor externally increases the shelf life and reliability of wireless sensors. Any vehicle stage or on-orbit fuel depot could greatly benefit from this technology.

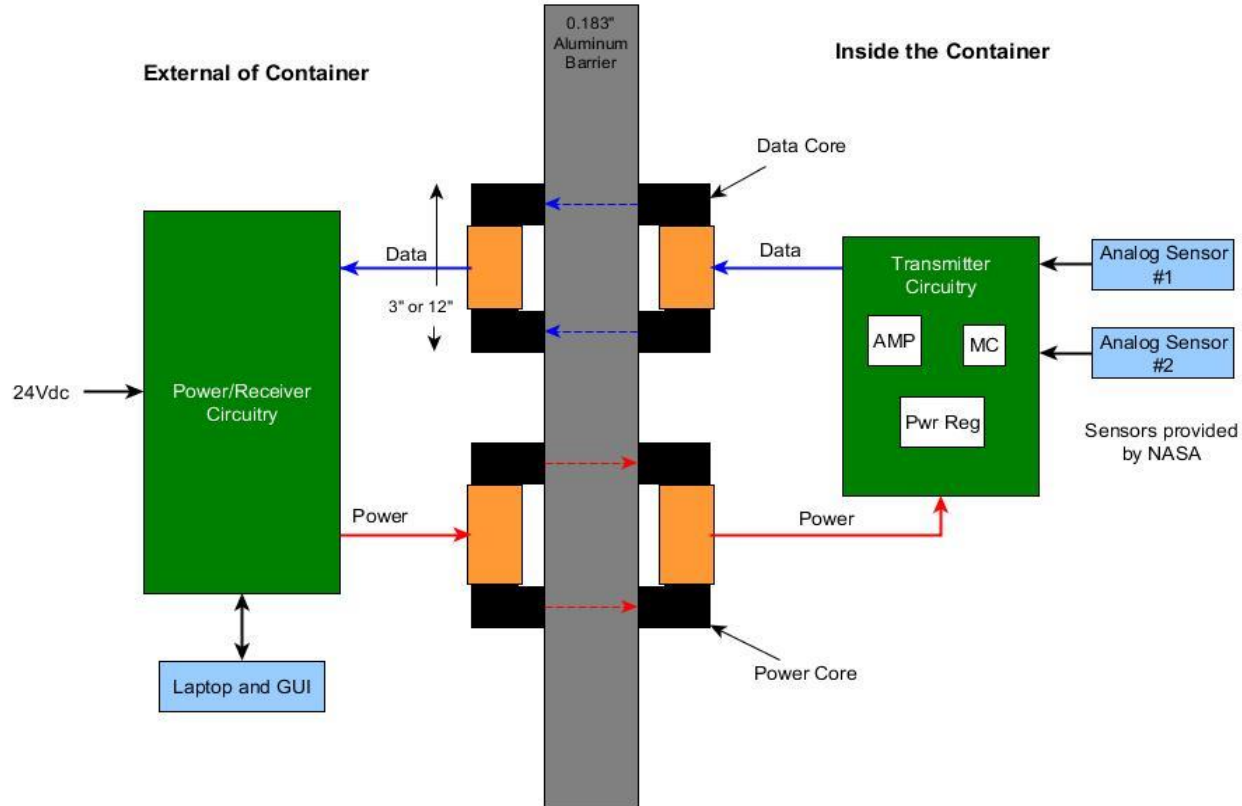
TE Funded Initiative to adapt an existing wireless sensor system for use with fuel/oxidizer tanks. Hydro Technologies developed a wireless sensor system that both receives data and transmits power by modulating magnetic fields. Their system works through metals, seawater, concrete, air, and layers of multiple materials. Deployed on USN Los Angeles class submarines and used through hull and used on oil pipelines.



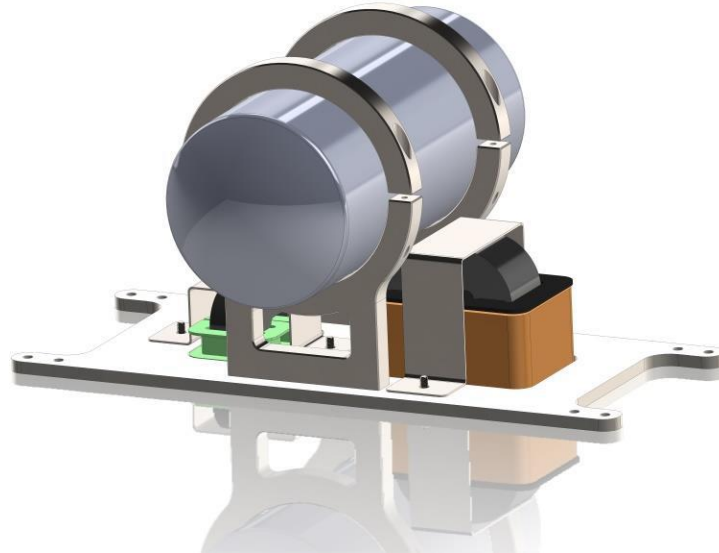
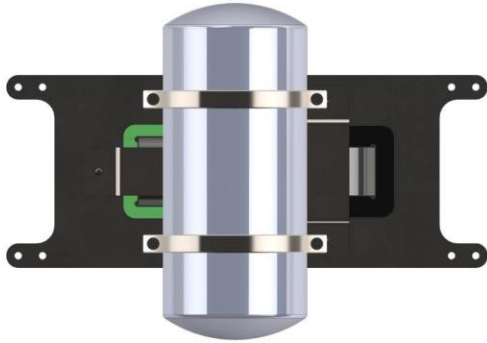
# Hydro-Tech NASA Gen2 Prototype

- Active digital system with two custom-made magnetic core sets, one for power and one for data. Basic temperature sensors will be used initially.
- Improvements in Gen2:
  - Increased data rate
  - Encapsulation of magnetic cores
  - Improved enclosure for interior electronics with heater
- Sealed aluminum container made with same aluminum alloy (2219-T8) and thickness (0.183") as SLS core stage oxidizer tank.
- Currently testing at MSFC.
- Planned cryogenic temperature testing using Liquid Nitrogen in East Test Area.

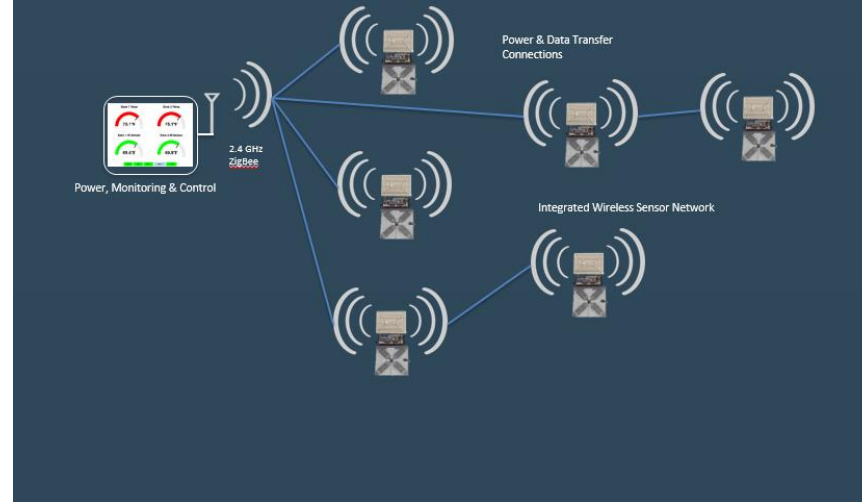
# Block Diagram



# Interior Electronics



Remotely charged, Multimode network, of Multi-sensor components



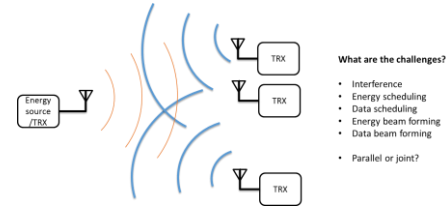
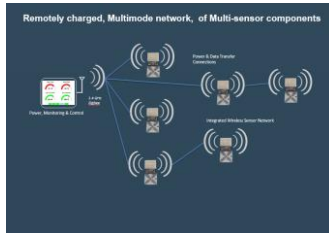
# Compact Wireless Power and Data Sensor System

Darren Boyd/ES36

Jason de Jongh/ESSSA



# Technical Overview & Project Scope



Power is one of the main obstacles in the implementation of wireless systems for Space Applications. Task is to investigate charging system to replace the need of batteries or augment batteries in sensor based measurement system with multiple transmitters and receivers. The system is to be designed to be modular where pieces can be replaced to meet different system requirements.

Project developed under research funding, this task is currently evaluating two types of wireless power transfer: magnetic coupling (short range) and RF power harvesting (longer range).

# Putting Pieces Together...



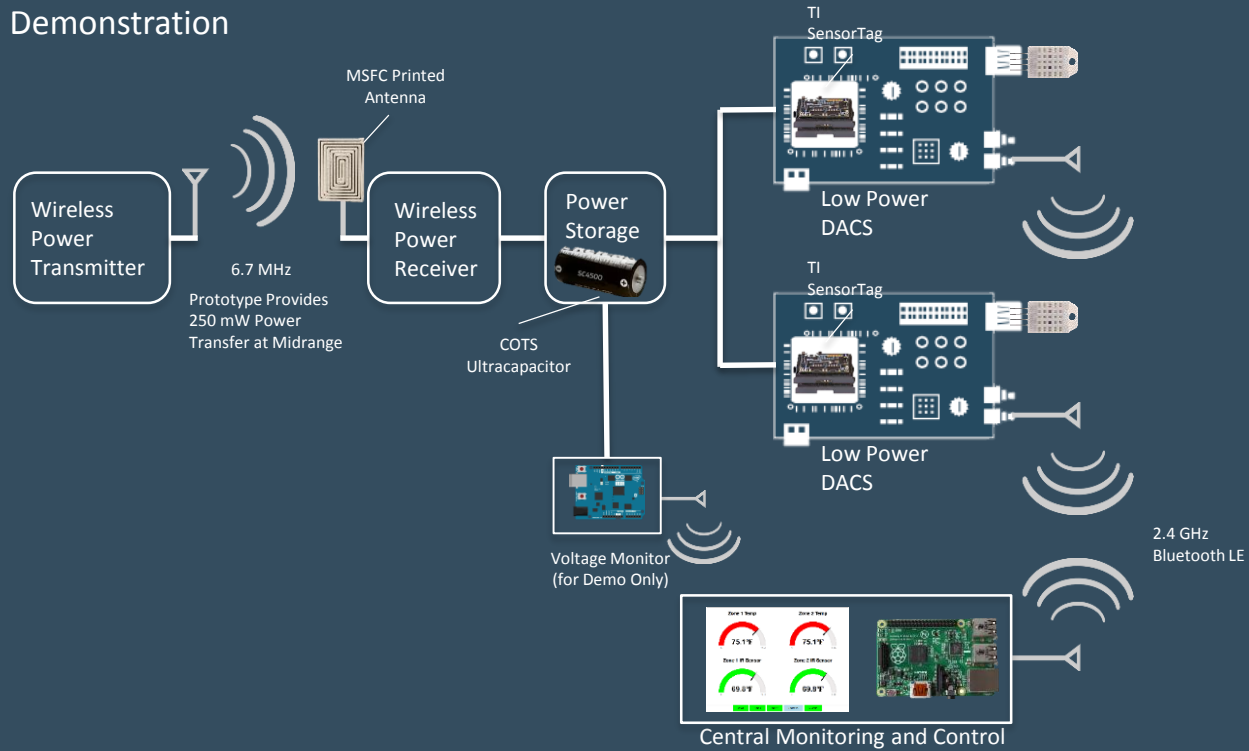
The Space Systems Department is working in technology areas that when combined could help advance sensor and data systems for aerospace systems. These systems are:

- Ultracapacitor
- Wireless Data Acquisition
- Wireless Power Capabilities
- Additive Manufacturing
- Mesh Networking

Remotely charged, Multimode network, of Multi-sensor components, capable of transmitting data and power wirelessly could be realized.

# First Steps Demo

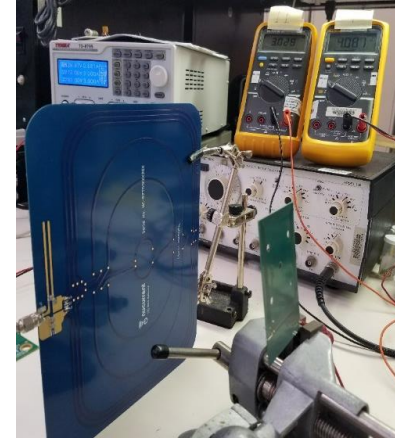
## Phase I Demonstration



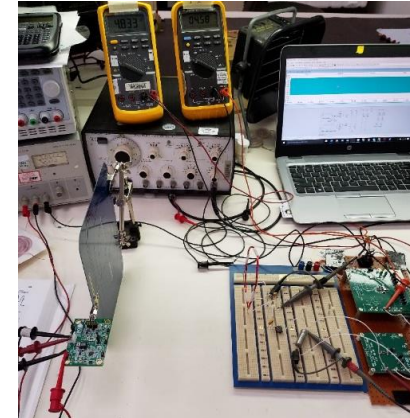
# Magnetic Resonant Inductive Coupling



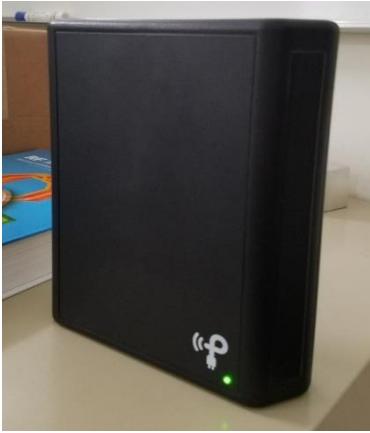
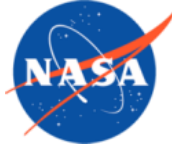
DC-DC converter with ultracapacitor  
maintain power to sensors after  
power transmission is turned off



Custom compact system  
designed, boards and parts orders



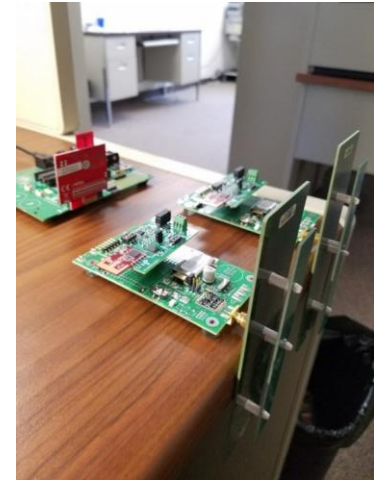
# Radio Frequency (RF) Harvesting



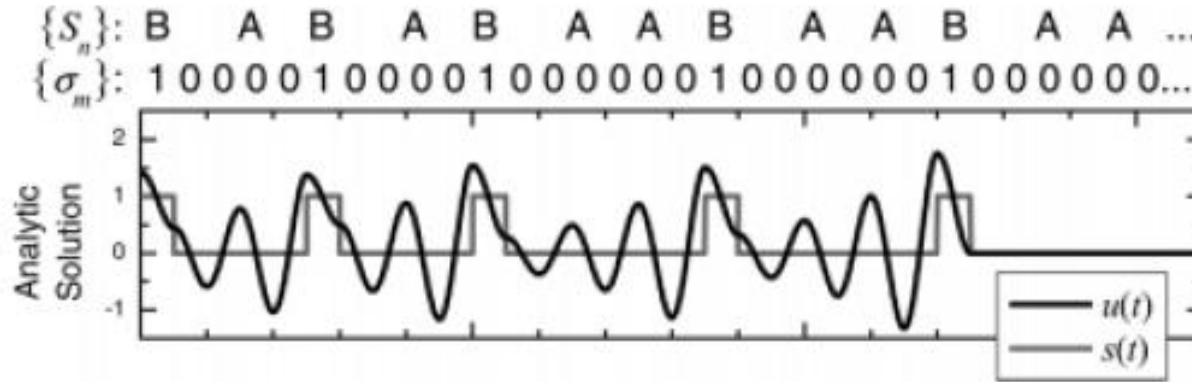
Characterizing commercial off the shelf system components

System optimization for our needs

Creating GUI for data analysis





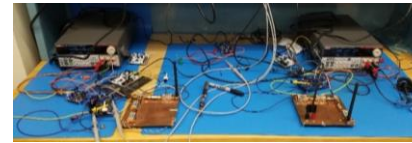
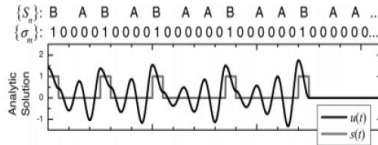


# Chaotic Oscillator Trajectory Communication

Darren Boyd/ES36

Dr. Dean and his students/Auburn University

# Technical Overview & Project Scope



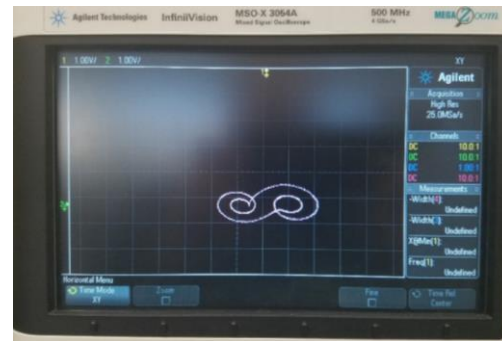
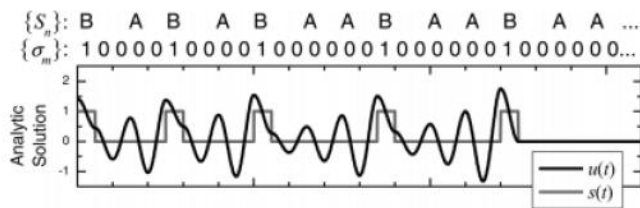
A unique approach to communication is currently being developed and is of great interest for high performance, smaller footprint, and more reliable wireless systems. This novel wireless communications system utilizes exact solvable chaotic oscillator circuits to encode and transmit data. This highly innovative method utilizes control techniques to steer a chaotic folded band oscillator toward distinct trajectories associated with binary values to transmit bits. These bits are then detected at the receiver using a matched filter and threshold comparator. This type of communication system provides several potentially game changing advantages to current approaches.

This approach was originally conceptualized and initially sponsored by the U.S. Army as a spin-off of their work using these chaotic oscillators and matched filters in radar systems. A team at Auburn University, through an initial SBIR, have taken the technology from concept to laboratory demonstration. We are now working with Auburn University and the Army to further test and develop the technology.

# What do we mean by chaotic oscillator communication?

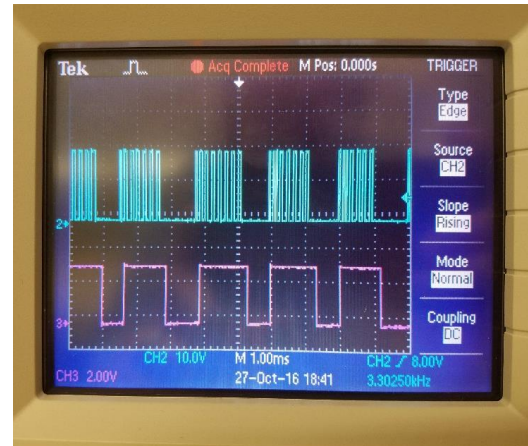


## Controlled folded-band chaotic oscillator



Phase space plot

## Mapping two distinct trajectories to binary values



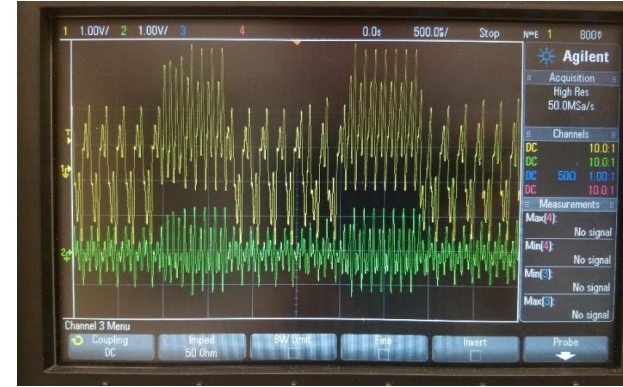
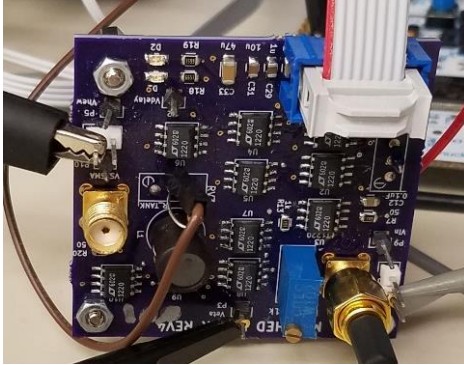
Concept developed by Army AMRDEC, systems developed by Auburn University

# Why Chaotic Oscillator Communication?



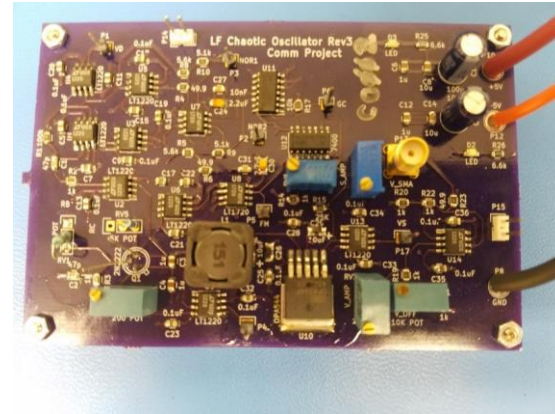
Optimal use of most efficient matched filters

Difficult signal detection



Theorized resistance to interference

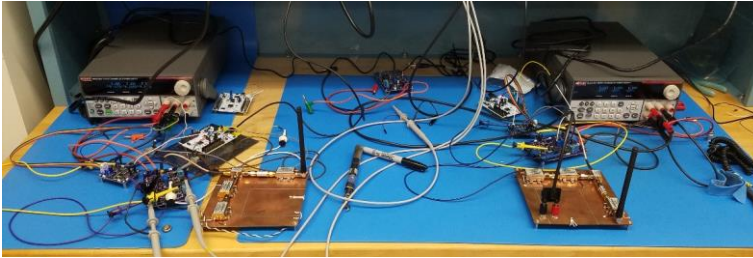
Relatively simple circuitry – fewer components





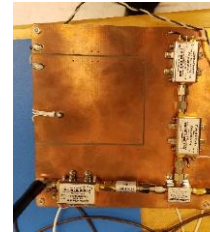
# What have we done?

Multiple systems up and running



Amplitude modulation communication

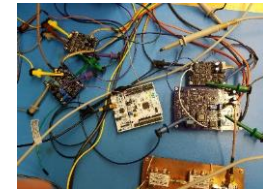
Systems working across the room



RS232 input



Revision 2 boards





# What have we done?



## Initial habitat testing

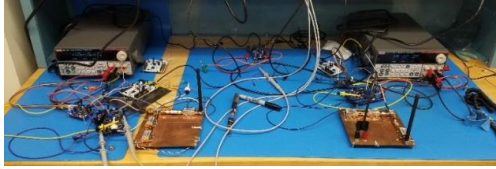


## Large habitat modifications



# What's next?

Further simultaneous  
system testing without AM



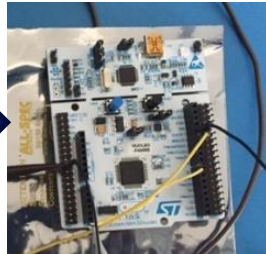
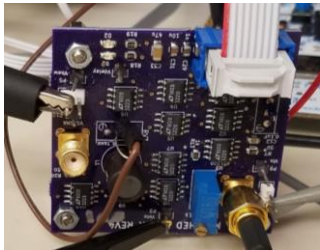
RF Performance/Bit Error Rate Testing



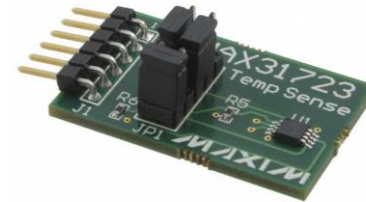
Continued habitat demonstrator testing



Continued testing with new  
software defined matched filters



Testing with integrated  
temperature sensor



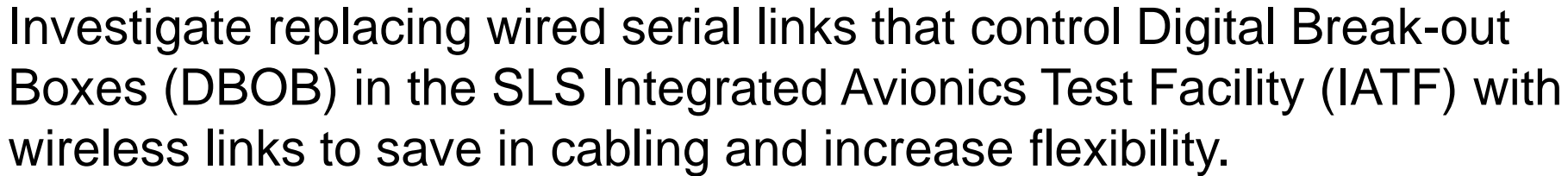
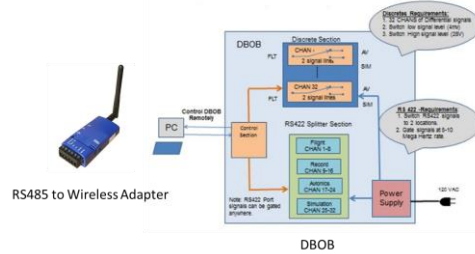


# Systems Integration Lab (SIL): Data Break-out Boxes

Garrick Merrill/ES36

Kosta Varnavas/ES36

David Zissa/ES53



Each string in the SLS IATF has 23 DBOBs for interfacing with the test software system. All DBOBs are daisy chained RS422 and require significant cable runs for command and communication. A wireless interface was proposed for the next generation DBOBs.



# DBOBs/SIL

- There are 23 DBOBs on each half cylinder at SIL
- Each RS422 connector has 8 ports with 10 MHz bandwidth
- Each one communicates with multiple devices analog/digital
- Signals range from 4mv to 40v DC







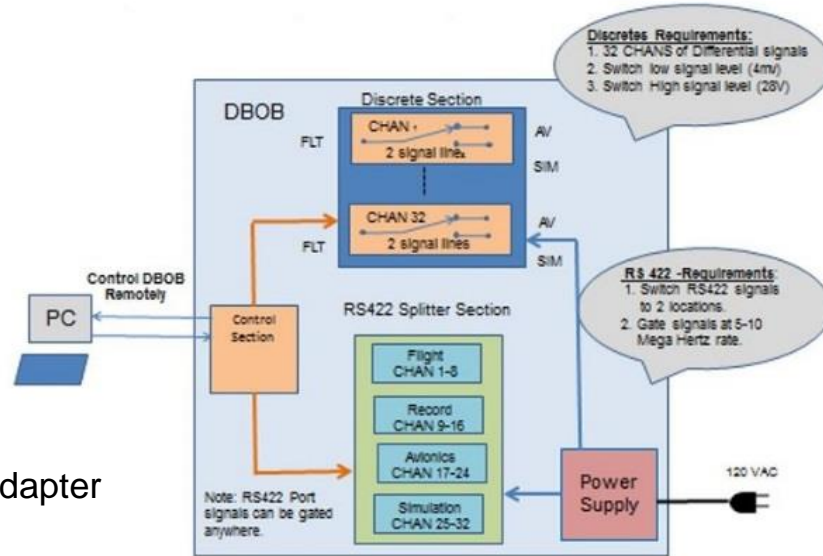
# Three phase approach

1. Add serial to 2.4GHz wireless adapters on two engineering unit DBOBs and modify IATF control software to talk through wireless interface
2. Assess the stability and resilience of the wireless links as well as additional links that can be wireless
3. Study applicability to Upper Stage IATF and full replacement of DBOB serial control wired links with wireless

# DBOB Interface



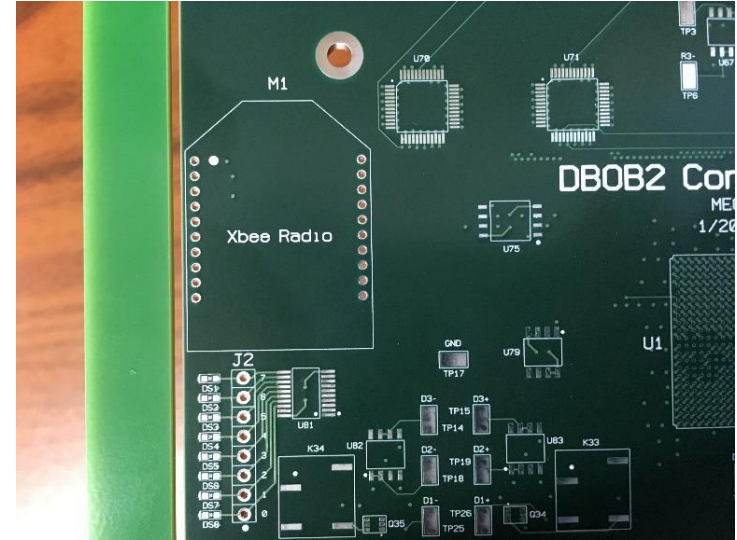
RS485 to Wireless Adapter

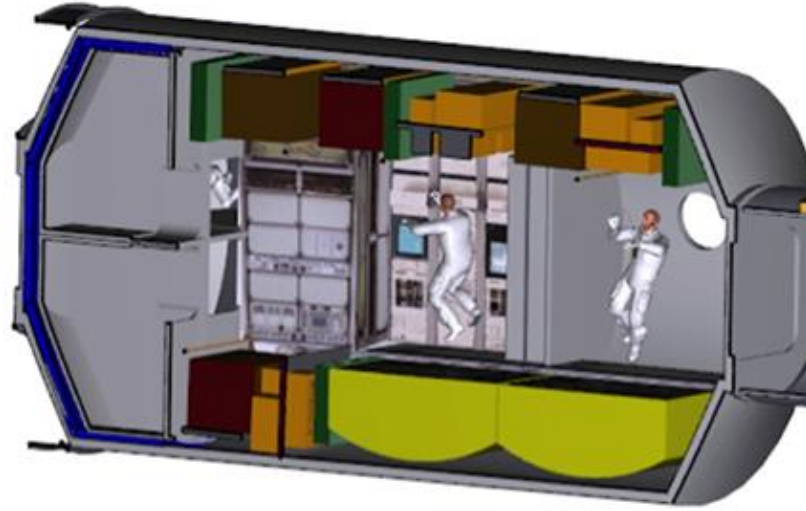


DBOB

# Current Work

- Redesign of DBOB in late 2016 changed plans
- New design could incorporate wireless inside the box
- Xbee Pro 900MHz radio chosen and incorporated into control board
- Antenna mounted on exterior of box
- Wireless is an option, original RS-485 links still exist
- New DBOB design in development testing.

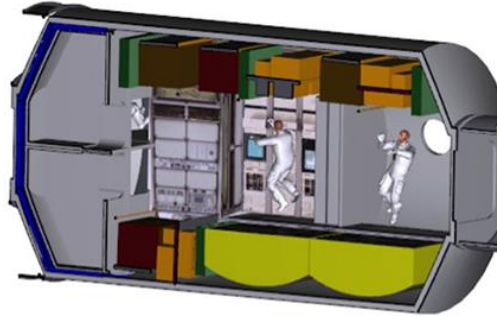
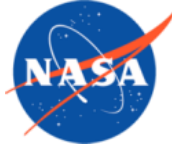




# Habitat Control System

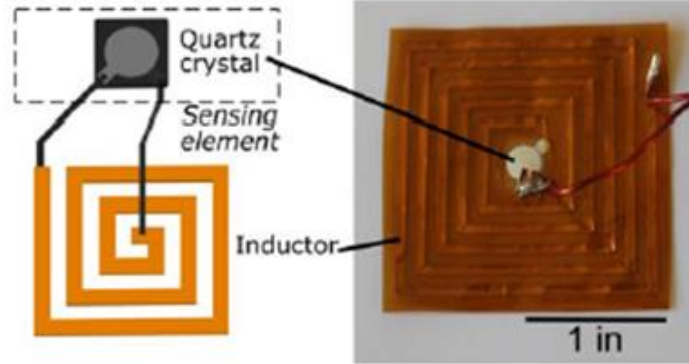
Andy Young/ES52

# Technical Overview & Project Scope



Develop a control system demonstration for a deep space habitat that includes sensors, crew displays, and a smart vehicle management system executing via Timeliner software.

Develop modular software framework to implement immediate project goals and allow for expanded capabilities.

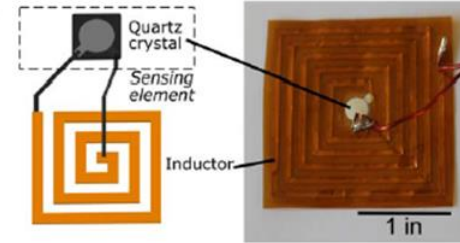
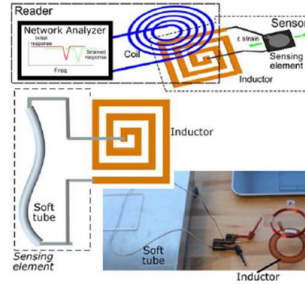


# Passive Wireless Strain Sensors: Structural Health Monitoring

Patrick Hull/ES21



# Technical Overview & Project Scope



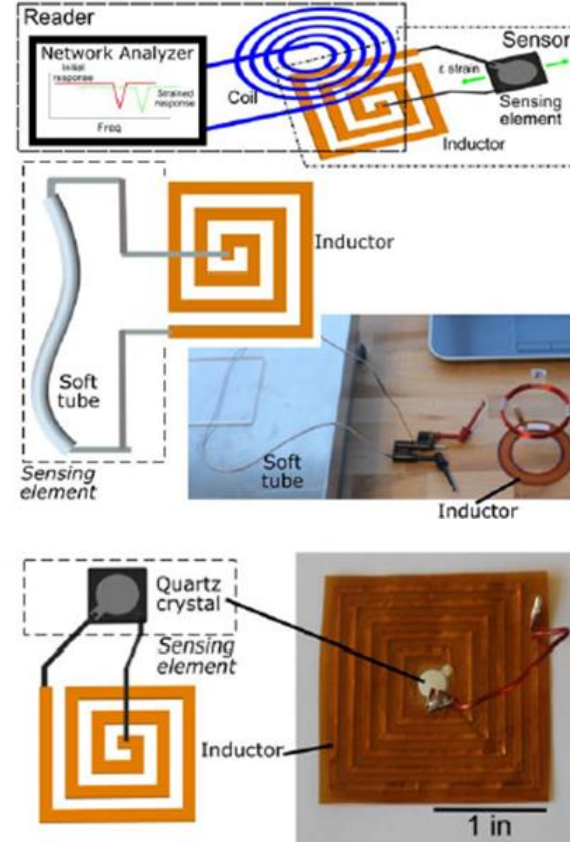
Characterization of structural health with wired, surface-mounted strain sensors is expensive and time consuming. To reduce costs and enable rapid characterization of mechanical strain of composites and additive manufacturing (AM)-based components for space systems, we are researching wireless strain sensors based on electromagnetic inductive coupling. The target outcome is a technology for structural health monitoring that uses light-weight sensors that might be embedded during fabrication (3D printing or layup) or added as surface mounts. The overarching goal of this effort is to develop a passive wireless strain sensor system for structural health monitoring during testing, transportation and pad health interrogation.

This project combines NASA's extensive experience in fabrication of composite structures, instrumentation for measuring mechanical strain on space structures, and testing of low-power wireless technology with university-based efforts in electromechanical modeling and fabrication. The resulting technology with passive devices and capabilities for direct incorporation into/onto components during manufacture will provide a marketable alternative to commercial wireless sensors/components that require onboard power (e.g., a battery), are bulky, or are not directly embeddable within structures during fabrication.

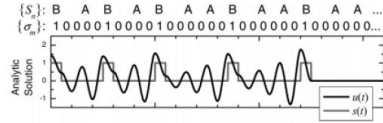
# Passive wireless system



Structural test



# Interests and Motivation



Second Generation  
Wireless Sensors



Chaotic Oscillator  
Trajectory Communication

Formation Flying



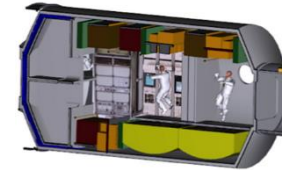
Systems Integration  
Lab (SIL)



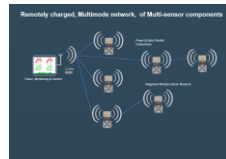
Fuel Tank Wireless  
Power and Signal System



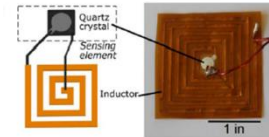
Habitat Control System



Compact Wireless Power  
and Data Sensor System



Passive Wireless  
Strain Sensors

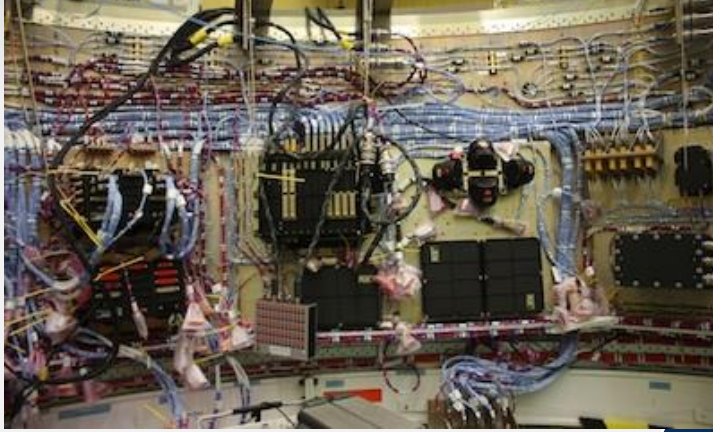


Questions?



# Backup Slides

# DRAWBACKS TO HARDWIRED SPACECRAFT BUS ARCHITECTURES



Failures of wires and connectors

Mass of cabling and electrical interfaces

Physical restrictions on wired sensor placements (tankage, bulkhead penetrations, etc)

Undesired ground loops on the communication paths; long wire runs acting as antennas



# ADVANTAGES OF WIRELESS TECHNOLOGY

Covers common-mode faults due to structural failure that may affect critical wiring!



Lower mass



Redundant data access nodes improves robustness



Low-power battery-powered sensor packages can last years and be placed in difficult locations for wires to reach (penetrations, high vibration, rotating structures and components)

# Interests and Motivation



- Currently there is a lot of development and interest in the RFID, passive type devices, for aeronautical vehicles and industry.
- Agency Roadmap strongly recommends the pursuit of wireless implementations including :
  - Wireless communication for science instruments and observatories to reduce mass associated with cabling, etc (TA8, 8.1.2)
  - Instrumentation and health monitoring needing less intrusive methods like acoustic, wireless, distributed, and MEMS sensors to improve mass, volume and cost metrics. (TA9, 9.4.6)
  - RFID instrumentation, wireless DAQs, and wireless power interfaces in ground and launch systems with the goal to reduce logistics management costs. (TA13)
- NASA Avionics Steering Committee 2014 Roadmap stated:
  - Wireless interconnect offers a host of advantages in NASA missions, eliminating the mass, power, and unreliability of cables and connectors, providing ease of integration and test, and allowing simpler reconfiguration, sparing, fault tolerance, and retrofitting of systems.

## And Recommended

- The development of RFID/SAW-based wireless instrumentation systems to reduce the weight of spacecraft cabling infrastructure and increase reliability & accessibility of sensors
- The development of mesh network protocols and standards for use in: space-to-space long-link systems with extreme propagation delays and outages; surface wireless systems with proximity-based quality of service and information assurance capabilities; and ad-hoc networking that can provide reliable end-to-end communications without carefully planned and scheduled link operations.



### Generation One

- 6 gauges all powered at same time.
- Strain gauged excitation voltage is straight off main battery rail.
- Op amp only has a 200 gain. This is a fixed gain set by on board resistor.
- No shunt or other method for onboard calibration.
- No Power Management.



### Generation Two

- Only 1 Gauge
- Each strain gauge has an independent constant voltage regulator driving the excitation voltage.
- Power management hardware.
- Op Amp has much larger and adjustable gains.
- Power management software.

# Wireless Deflection Sensors

